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Mathematical and computational studies have been carried out on problems of theoretical aerodynamics. Shock free bodies and optimum critical airfoils have been considered in transonic theory, optimum three-dimensional lifting wings in hypersonic theory. Stability and transition of boundary layers has been analyzed according to triple deck theory. The Benjamin-Davis-Acrivos equation has been derived and it has been shown how solitons can lead to chaotic motion.

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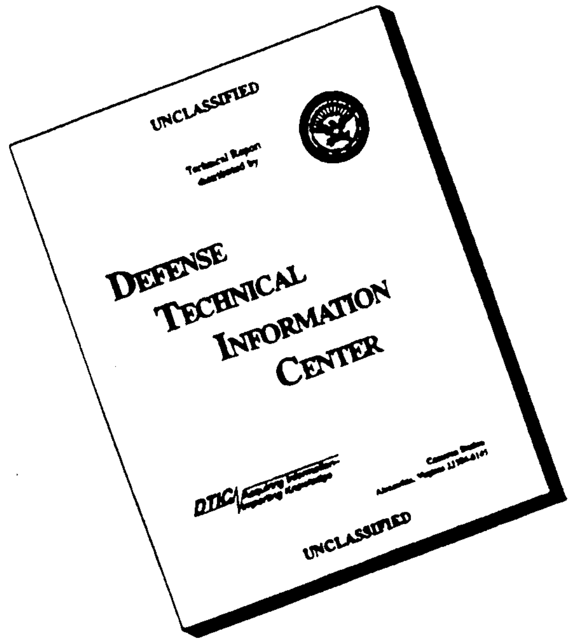

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Final Technical Report

January 11, 1996

Theoretical Aerodynamics

AFOSR Grant AF49620-93-1-0022DEF

Introduction

The objective of the research of the past three years has been to study and analyze a variety of mathematical problems arising in aerodynamic theory. The two principal areas under study were classical aerodynamics and stability and transition in boundary layers. Classical aerodynamics encompasses mainly transonic, second-order supersonic, and hypersonic theory. Stability and transition in boundary layers were studied on the basis of the asymptotic triple-deck theory. In general our methods combine numerical and asymptotic approaches. Our general aim is two-fold: first, to formulate new and significant problems for aerodynamic theory and second to generate new mathematical and computational ideas useful for solving these problems. The main results are documented in the publications (see below).

1. Transonic Aerodynamics

Studies leading to the design of optimum non-lifting and lifting critical airfoils have been completed. These airfoils have for a given constraint, such as thickness, the maximum critical (free-stream) Mach number. They are characterized by an arc on the surface on which the flow is sonic but there is no supersonic region or shock wave. These airfoils have better performance in this sense than conventional airfoils. This work in continuing in the study of cascades of such airfoils. Theory and calculations for this problem were carried out in the hodograph plane.

Shock-free bodies of revolution which are not symmetric fore and aft were designed. These are analogous to supercritical airfoils. The analysis and computation were carried out in a special hodograph plane for transonic small-disturbance theory (TSDT). These body shapes have a special utility because of the transonic area rule which states that for any configuration the drag (zero at design) is the same as that of the equivalent (same distribution of cross-section area) body of revolution.

Some simple examples for unsteady (TSDT) were studied in order to gain insight into the behavior of solutions to these equations. In particular, the problem of the flow due to the sudden deflection of a thin wedge was analyzed and it was shown how a non-uniformity of linearized theory leads to a transonic region in space-time. A similarity solution was formulated and a computational method was implemented to obtain the solution for the exactly sonic case. Subsonic and supersonic cases are natural extensions. The problem is relevant to the glancing incidence of a shock or Mach reflection.

The shock wave of a sonic boom was studied as it passed through a turbulent field. It was shown that transonic theory is necessary to describe the changes in the rather weak shock due to turbulence. The correct generalized TSDT equation was derived. Numerical calculation were carried out which showed substantial changes in the sonic boom compared to that in a non-turbulent atmosphere.

2. Hypersonic

The central problem considered was the design of optimum 3D hypersonic wings, according to hypersonic small deflection theory (HSDT). The analogy of 3D HSDT with the 2D unsteady Euler equation was used to set up a computer code. A series of problems was (and will be) considered leading to optimizing lift to drag ratio. Variations in conical twist were studied.

3. Stability and Transition; Separation

The utility of the triple-deck approach to the study of stability of boundary layers in various circumstances, subsonic, transonic, supersonic has been demonstrated. This asymptotic theory for large Reynolds number shows all essential features of the instability and transition process in both linear and nonlinear regimes. A systematic derivation of the Benjamin-Davis-Acrivos equation was given. The existence of solitons for this equation was documented and it was shown how a chaotic motion arises from this beginning.

Vortex-roughness interaction in the boundary-layer was studied and this showed great differences between wave packets and simple harmonic wave trains. Wave packets were shown to amplify extremely rapidly in contrast to wave trains.

The Landau-Goldstein singularity at a separation point of a boundary layer was analyzed. New possibilities for the behavior, compared to earlier results, were presented.

Publications

1. Julian D. Cole, Donald Schwendeman, M.C.A. Kropinski, "Hodograph Design of Lifting Airfoils with High Critical Mach Numbers," *J. Theoretical and Computational Fluid Dynamics* 7, 1995, pp. 173-188.

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11. E.V. Bogdanova-Ryzhova & O.S. Ryzhov, "On singular solutions of the incompressible boundary-layer equation including a point of vanishing skin friction," *Acta Mechanica*, Vol. [Suppl]4, 1994, pp. 27-37.

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Theses

1. M.C.A. Kropinski, "A Study of Optimal Critical Airfoils," Ph.D. Thesis, Rensselaer Polytechnic Institute, June 1993.

2. R. Buckmire, "Design of Shock Free Transonic Slender Bodies of Revolution," Ph.D. Thesis, Rensselaer Polytechnic Institute, December 1993.

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